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Penetrator-deployed mass spectrometers for volatiles analysis at the moon

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Introduction: The polar regions of the Moon have long been known to be possible traps for solar system volatiles due to the low temperature of permanently shadowed areas. These permanently shadowed regions are cold enough to store any volatiles that enter them [1,2]. Volatiles trapped there are of interest because they record those released from the interior of the Moon during its geologic evolution, plus species derived from the solar wind, cosmic dust, and comet/asteroid bombardment. Therefore such PSRs preserve a record of the evolution of the Moon, the history of the sun, and the nature of comets/asteroids.

Arguably the most compelling evidence for lunar polar volatiles comes from the Lunar Crater Observation and Sensing Satellite (LCROSS) mission [3] where an un-instrumented spent upper rocket stage was impacted into the permanently shadowed Cabeus crater near the lunar south pole. The resulting impact was observed by instruments on LCROSS, and the results led to the deduction that the concentration of water ice at the impact site was 5.6 ± 2.9 % by mass [4]. However, many unanswered questions remain about the L-CROSS observations and arguably the next stage in understanding polar volatiles is to determine the species and their form and distribution (horizontally and vertically) through in-situ measurements. It is therefore natural that mass spectrometer based instruments will form the integral future payloads.

Penetrator deployment systems: In the near future the ESA PROSPECT package which is proposed for the Luna-27 lander [5] will perform in-situ volatile extraction and characterisation on the surface of the moon. However, PROSPECT is a complicated package and by virtue of performing its soft landing it may contaminate or modify its environment. In contrast, penetrators (Figure 1) are small probes that offer the opportunity to gain access to surface and sub-surface material at high-speed from orbit [6] without the need for drilling or excavation equipment or at low-speed from soft landers [7]. Multiple penetrators further offer geographically spaced investigations and mission redundancy.

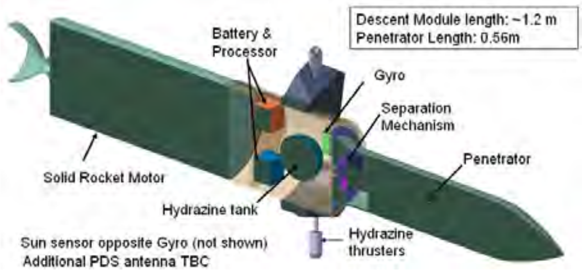

Figure 1: High-speed penetrator de-orbit and ejection system

Penetrator deployed mass spectrometers: The Ptolemy [8,9] Ion Trap mass spectrometer (Figure 2), is on-board the European Space Agency's Philae lander and returned the first in-situ volatile measurements from the surface of a comet in 2014. Due to its simple and rugged design, this type of instrument is well suited for penetrator deployment platforms. An impact tolerant version of the Ptolemy mass spectrometer has been developed by The Open University. The instrument will allow in-situ volatile characterisation following penetrator deployment. Figure 3 shows the prototype high-speed compatible instrument and a miniaturised 30 mm diameter instrument for accommodation in a low-speed ground penetrating mole device.

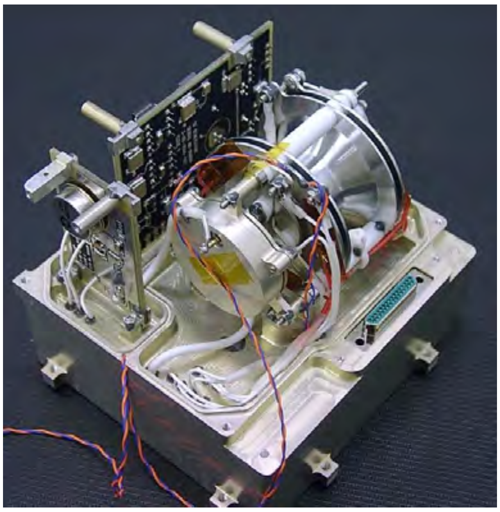
Figure 2: The Ptolemy Ion Trap Mass Spectrometer instrument

Figure 3: (left) The impact tolerant penetrator deployable mass spectrometer (right) the mole deployable mass spectrometer

Impact testing: High-speed testing of the mass spectrometer has been performed under a UK-led penetrator testing programme. The objective of these tests was to demonstrate survivability of the penetrator shell and to assess the impact on instrument subsystems. The impact tolerant ion trap mass spectrometer was part of the payload. An Impact speed of 310 ms^{-1} was achieved with a solid rocket accelerated instrumented penetrator (Figure 4). A Penetration depth of 3.9 m into a sand target was achieved with substantial ablation to nose and belly (Figure 4)

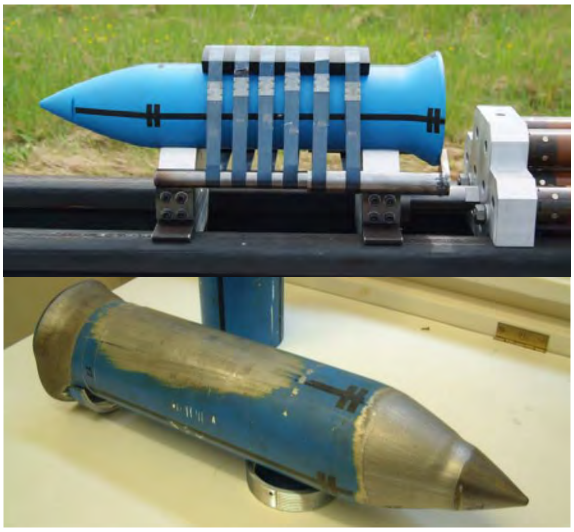

Figure 4: (Top) Instrumented penetrator prior to and (bottom) post impact penetrator shell

Results: The impact tolerant mass spectrometer survived an impact event of approximately 20000 g. Mass spectrums of PFTBA reference compound and Xenon (Figure 5) at a partial pressure of 1×10^{-7} mbar are shown following the impact testing.

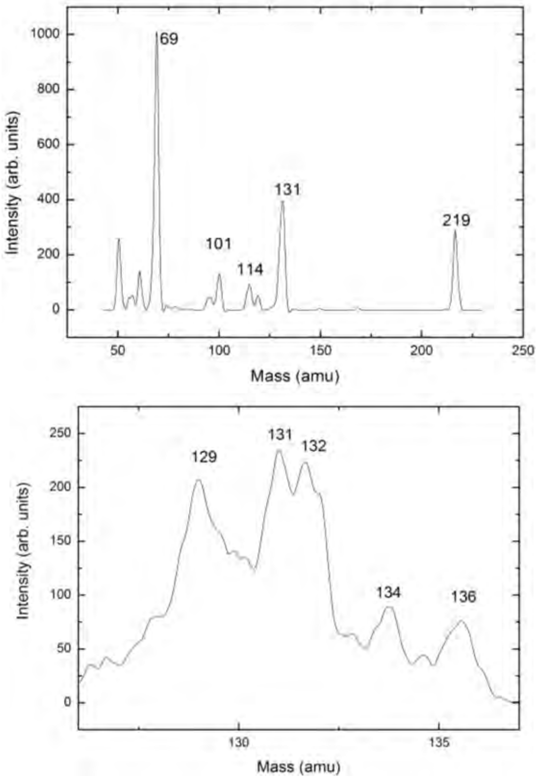

Figure 5: (Top) mass spectra of PFTBA reference compound and (bottom) Xenon

Future Work: The mass spectrometer instrument has been re-designed and miniaturised further for incorporation into a sub-surface penetrating mole device. Future testing will be carried out with low-speed mole penetrators to investigate volatile content with depth of lunar analogues

Summary: A rugged mass spectrometer has been developed, impact tested and shown to survive the forces consistent with deployment in high-speed penetrator missions such as L-DART [10]. Deployment by penetrators, either high speed or low-speed opens up the future possibility of accessing regions of the moon such as PSRs that are currently inaccessible to soft landers.

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